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14. ABSTRACT
The objective of this effort was to evaluate automatic particle counters for use in monitoring aviation fuel cleanliness at three Army Heliports located at Fort Rucker. Online and and laboratory instrumentaiton were both evaluated during the week long demonstration. Based on this evaluation it was determined light obscuration particle counter technologies are able to properly measure solid particles and provide an indication of particulate content levels present in fuels, and may be an appropriate replacement for the Army's existing filter effectiveness testing.

15. SUBJECT TERMS
Fuel, JP-8, Automatic Particle Counter, cleanliness, free water, Diesel

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-Technical Report-

Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection – Fort Rucker

Joel Schmitigal

Jill Bramer

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June 2013

U.S. Army Tank Automotive Research, Development, and Engineering Center
Detroit Arsenal
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Force Projection Technology

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Acknowledgements

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1. **Introduction**

Fuel quality assurance is accomplished by conducting periodic fuel sampling for the condition monitoring of aviation fuel by detecting, measuring, and reporting the levels of contaminants in the fuel. The currently accepted methods for measuring particulate and free water contamination of fuel supplies include:

- ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
- ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels
- ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

The current methods have several drawbacks including operator subjectivity, lack of detailed analysis, limitations in providing reliable data, and the turn-around time needed to get the test results.

The U.S. Army maintains the mission of providing quality fuel to all U.S. and Allied troops in tactical environments. Presently, requirements as outlined require a dedicated group of specifically trained fuels personnel to perform several tests per day per installation, looking for traces of sediment and water in the fuel (1)(2)(3).

Current standards, such as MIL-STD-3004, Department of Defense Standard Practice for Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products and Field Manual No. 10-67-2, Department of the Army Manual for Petroleum Laboratory Testing and Operations, specifies limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (PPM) (2) and particulate matter contamination cannot exceed 2.0 mg/L for Intra-Governmental transfer receipts and 1.0 mg/L on issue to aircraft, or up to 10 mg/L for product used as a diesel product for ground use (1). Free water contamination (droplets) may appear as fine droplets or slugs of water in the fuel systems. The particulate matter found in field fuel systems varies in shape and is commonly found in the 5 to 40 micron size range. Common particulate matter includes silica, rust, metal shavings, fibrous materials, coatings material including paint, elastomeric materials, hydrocarbon/oxidation materials, and any other solid matter. At a minimum free water and particulate by color (as specified in the appendix of ASTM D2276) are checked daily, while filter effectiveness is checked every 30 days by gravimetric analysis (ASTM D2276).

The use of particle counting and automatic particle counters is prevalent in the hydraulics/hydraulic fluid industry. The International Organization for Standardization (ISO) has published several methods and test procedures for the calibration and use of automatic particle counters. The transition of this technology to the fuel industry is relatively new and several organizations (military and commercial) have conducted testing to ensure the transition from the hydraulic fluid market to fuels is viable.

In recent years, the United Kingdom (UK) based, Energy Institute (EI) published standards relating to fuel quality measurement using sensors. The first edition of EI 1570 Handbook on electronic sensors for the detection of particulate and/or free water during aircraft refueling was published in August 2012, and the second edition of EI 1598 Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel was published in February 2012. In addition to the handbooks, the EI has also developed three (3) standard test procedures and methods for evaluating the particulate matter of fuels using electronic sensors; IP 564, IP 565, and IP 577.

- IP 564 – Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method
- IP 565 – Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method
- IP 577 – Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction

Military aviation fuels meeting the requirements of DEF STAN 91-91 (UK) (4) and MIL-DTL-83133 (US) (5) both include a report only requirement for particle counting. Particulate contaminate limits using particle counters are being developed as test programs and field demonstrations are in progress.

The U.S. Army and U.S. Navy have conducted laboratory evaluations of particle counter technologies for fuel contamination monitoring. The particle counters tested were unable to adequately distinguish between free water and sediment contamination. Conclusions from the laboratory evaluation indicated that particle counters cannot replace current technology where quantification of both free water and sediment contamination is required. However, this technology showed significant promise for monitoring overall fuel quality. To simplify the reporting of particle counter data, the International Organization for Standardization created Cleanliness code 4406:1999 (6). Several interested parties, both commercial and military, have proposed limits based on light obscuration particle counting technologies based on ISO 4406, provided in Table 1 and references (7)(8)(9)(10)(11)(12)(13)(14). As a result of the laboratory testing conducted, the U.S. Army has proposed a working cleanliness limit (based on ISO 4406) of 19/17/14/13 utilizing the 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c) size channels (9). The U.S. Army has included the 30µm size to detect free water in the fuel.

	Receipt	Vehicle Fuel Tank	Fuel Injector
Aviation Fuel			
DEF (AUST) 5695B		18/16/13	
Parker	18/16/13	14/10/7	
Pamas/Parker/Particle Solutions	19/17/12		
U.S. Army	19/17/14/13*		
Diesel Fuel			
World Wide Fuel Charter 4th		18/16/13	
DEF (AUST) 5695B		18/16/13	
Bosch/Cummins		18/16/13	
Donaldson	22/21/18	14/13/11	12/9/6
Pall	17/15/12	15/14/11	12/9/6 11/8/7

Table 1. Proposed Particle Counter Limits
***addition of 30 micron channel proposed by U.S. Army for detection of free water.**

2. **Project Background**

Defense Logistics Agency – Energy (DLA-E) funded a Tri-Service Field Evaluation of Automatic Particle Counters. Each Service chose two (2) locations to conduct testing. The U.S. Army chose to conduct testing at Campbell Army Airfield (CAA) at Fort Campbell, KY(15), and three Army Heliports (AHP) at Fort Rucker, AL. This report will only contain the test data collected 15-18 April 2013 at Hanchey AHP, Lowe AHP, and Molinelli Stagefield AHP.

Once the locations were selected, TARDEC conducted site surveys at both locations in January/February 2013, to document the fuel distribution systems, ensure connections were available for the instruments, and to identify a location for testing of the laboratory based instruments.

The field evaluation included two types of particle counters: on-line instruments and portable laboratory based instruments. The online instrument chosen for this demonstration was the Parker Hannifin IcountOS, Figure 1, which will be called IOS throughout the report. The IOS instruments were designed to plug into existing sampling ports and extract a fuel sample during fuel flow. These instruments are capable of pumping the fuel back into the supply lines; thus creating no waste fuel. The IOS instruments run every 2 minutes and automatically collect and store data. Ideally, these instruments can be left in the field to monitor and collect data for fuel transfers. Due to the low frequency of fuel transfers at the U.S. Army locations, the IOS units were configured to only pull fuel samples from the supply lines and were initiated manually by the operators for each data set. The IOS units were moved from location to location as needed.

The second type of particle counter utilized in this demonstration consisted of laboratory based instruments used to evaluate contamination levels of bottle samples taken from select locations at Fort Rucker. The laboratory instrumentation, Figure 2, utilized included:

- Parker Hannifin ACM20 instrument meeting IP 564
- Pamas S40 AVTUR instrument meeting IP 565
- Stanhope-Seta AvCount instrument meeting IP 577

All instruments were calibrated to ISO 11171, and reported cleanliness codes based on ISO 4406. Cleanliness levels were represented by 4µm, 6µm, and 14µm size channels respectively. The 30µm channel was also reported for the Parker Hannifin ACM20 instrument and the Stanhope-Seta AvCount instrument because the prior work has indicated that the 30µm channel may contain pertinent information relating to free water content (9). During this evaluation, the Pamas S40 AVTUR instrument did not have the capability of providing 30µm channel data.

Figure 1. Parker IcountOS inline instrument

Figure 2. Laboratory instrumentation 2 Pamas S40 AVTUR instruments (foreground), Stanhope-Seta AvCount (back left), 2 Parker Hannifin ACM20 instruments (back right)

A sampling manifold was constructed to ensure the particle counters tested the same fuel from the same location in the bottle sample. Additionally, each bottle sample was hand rolled for 1 minute to ensure the particles were homogeneously distributed throughout the sample without introducing air bubbles. Each bottle sample was tested in duplicate and agitated in between runs.

3. **Approach**

The field demonstration at Fort Rucker was conducted during the week of 15-18 April 2013. The demonstration focused on fuel receipts and issues at Hanchey AHP and Lowe AHP, with supplemental data obtained at Molinelli Stagefield AHP. The delivery/movement of fuel dictated where and when the testing took place.

Fort Rucker receives and stores JP-8 in storage tanks located at select AHP around the installation. Hanchey AHP maintains four 42,000 gallon fuel storage tanks, while Lowe AHP has two 160,000 gallon tanks. The JP-8 is delivered by commercial fuel tanker (averaging between 7,200-7,500 gallons per tanker) from Montgomery, Alabama.

Upon receipt, the JP-8 fuel is filtered and then and transferred into one of the onsite storage tanks the fuel is then filtered once again before being dispensed into refueling trucks, or being sent to the hydrant system in the case of Molinelli Stagefield AHP. Figure 3 provides a graphical layout the fuel distribution system and test points at Fort Rucker.

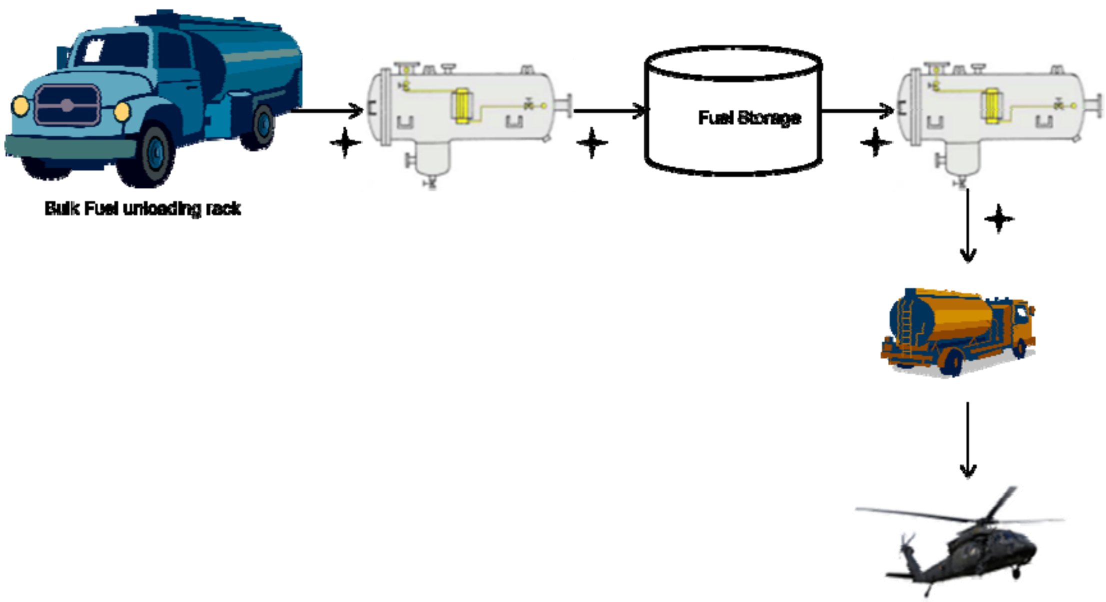

Figure 3. Fort Rucker Fuel Systems

4. **Analysis**

TARDEC made 35 unique particulate fuel measurements during a 4 day demonstration at Fort Rucker from 15 April to 18 April 2013, from commercial receipt, refuel truck issue, and hydrant system issue locations, at three AHP's located across the Army installation, details of these measurements are provided in Table 2.

Sample #	Date	Time (EST)	Sample Source/Location
1	15-Apr-2013	930	Hanchey AHP Reciept upstream
2	15-Apr-2013	930	Hanchey AHP Reciept downstream
3	15-Apr-2013	1340	Hanchey AHP Issue upstream
4	15-Apr-2013	1300	Hanchey AHP Issue downstream
5	15-Apr-2013	1300	Hanchey AHP Issue upstream
6	15-Apr-2013	1340	Hanchey AHP Issue downstream
7	15-Apr-2013	1400	Hanchey AHP Reciept upstream
8	15-Apr-2013	1400	Hanchey AHP Reciept downstream
9	15-Apr-2013	1435	Hanchey AHP Issue upstream
10	15-Apr-2013	1435	Hanchey AHP Issue downstream
11	15-Apr-2013	1355	Hanchey AHP Issue upstream
12	15-Apr-2013	1355	Hanchey AHP Issue downstream
13	16-Apr-2013	800	Hanchey AHP Reciept upstream
14	16-Apr-2013	800	Hanchey AHP Reciept downstream
15	16-Apr-2013	930	Hanchey AHP Reciept upstream
16	16-Apr-2013	930	Hanchey AHP Reciept downstream
17	16-Apr-2013	1300	Hanchey AHP Issue upstream
18	16-Apr-2013	1300	Hanchey AHP Issue downstream
19	16-Apr-2013	1300	Hanchey AHP Reciept upstream
20	16-Apr-2013	1300	Hanchey AHP Reciept downstream
21	17-Apr-2013	915	Molinelli Stagefield AHP air pad 11
22	17-Apr-2013	938	Molinelli Stagefield AHP air pad 11
23	17-Apr-2013	1330	Lowe AHP Reciept upstream
24	17-Apr-2013	1330	Lowe AHP Reciept downstream
25	17-Apr-2013	1408	Lowe AHP issue upstream
26	18-Apr-2013	840	Lowe AHP Reciept upstream
27	18-Apr-2013	840	Lowe AHP Reciept downstream
28	18-Apr-2013	930	Lowe AHP Reciept upstream
29	18-Apr-2013	930	Lowe AHP Reciept downstream
30	18-Apr-2013	1347	Lowe AHP Reciept upstream
31	18-Apr-2013	1347	Lowe AHP Reciept downstream
32	18-Apr-2013	1320	Lowe AHP Issue upstream
33	18-Apr-2013	1320	Lowe AHP Issue downstream
34	18-Apr-2013	1320	Lowe AHP Issue upstream
35	18-Apr-2013	1320	Lowe AHP Issue downstream

Table 2. Fort Rucker particulate analysis samples

TARDEC tested both receipt fuel being delivered onto the base from commercial fuel trucks from Montgomery, Alabama and issue fuel that was being delivered to the flight line. For each tanker (unless specified), testing included free water determination, matched weight monitor testing for particulate contamination by gravimetric analysis, IOS particle counting, and laboratory particle count instrument by bottle method. TARDEC employed the use of the

Aviation Fuels Contamination Test Kit (AFCTK) to pull Aqua-Glo (free water) samples, matched weight monitors for gravimetric analysis, and the 1 gallon bottle sample. Free water determination was conducted in accordance with (IAW) ASTM D3240. A one-liter sample was filtered through the Aqua-Glo pad and tested using the D-2 Incorporated JF-WA1 Hydro-Light digital pad reader. Particulate contamination determination was conducted IAW ASTM D2276. In most cases, the collection vessel vents would begin to leak and the total volume of fuel filtered through the monitor ranged between 250-500mLs. Once the vessel began to leak, TARDEC terminated the sample collection and notated the total volume. Once sample collection was complete, the residual fuel was removed from the monitor, the plugs were replaced, the filter was placed in a re-sealable bag, and labeled for future analysis. All monitors were shipped back to TARDEC for analysis. IOS instruments were connected to the sample ports and the pumps were manually initiated to begin operation and data collection. Finally, a one (1) gallon fuel sample was collected from each tanker for testing the laboratory based instrument. Due to the small volume (2500 gallons) of some of the refueling trucks; complete data sets were not able to be developed for all of the issue samples. All fuels sampled had a free water content of 0.1 ppm or less, so free water droplet contribution to particle counts will not be evaluated or further discussed in this paper.

4.1. Fuel receipt data analysis

When performing an analysis of particle counts the smallest channel size is a crucial data point for reference as the >4µm channel cumulatively encompasses all the particulates present in the fuel greater than 4µm, for all instrumentations utilized in this demonstration the smallest channel is counts >4µm. Figure 4 graphically shows the 4µm ISO code for the laboratory instruments and the initial IOS data for the receipt samples upstream of the filter separator, while Figure 5 shows the corresponding data downstream of the filter separator. The IOS instruments are reading 1 to 2 iso codes lower than the laboratory instruments for 5 of the 8 samples measured. The difference in the 4µm channel between the two types of instruments is believed to be caused by bottle contamination.

Also seen in Figure 4 thru Figure 7, the ACM20 instrument (red line) is reporting lower particle counts in the 4µm and 6µm channels than the Pamas S40 AVTUR instrument and the Stanhope-Seta AvCount instrument. TARDEC attributes the difference to calibration since the ACM20 instruments were calibrated to the lower end of the tolerance allowed by ISO 11171. However, the overall trending of the ACM20 instrument with the Pamas S40 AVTUR and Stanhope-Seta AvCount instrument indicates that values reported from all the instruments are valid measurements. Detailed ISO code data is provided in Table 3

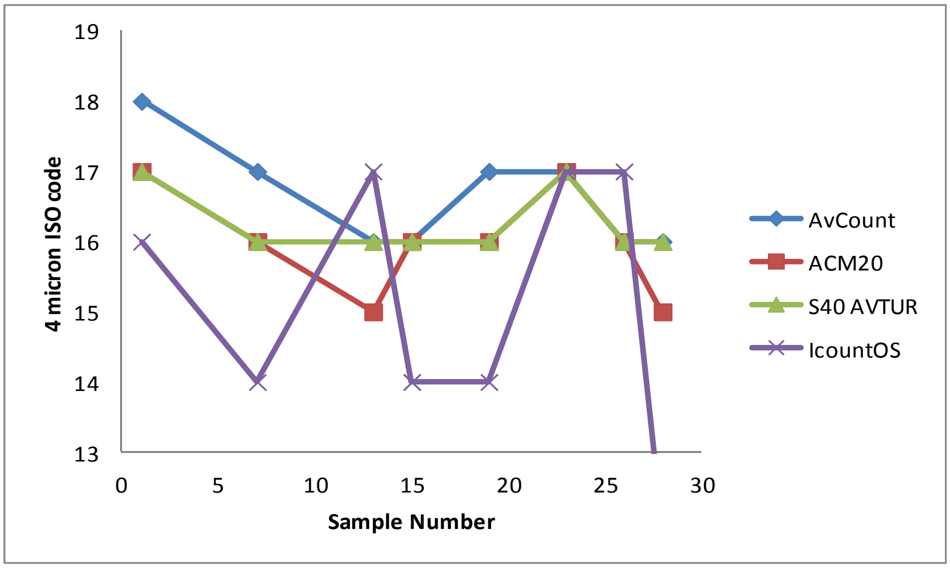

Figure 4. Fort Rucker upstream receipts 4µm ISO code data.

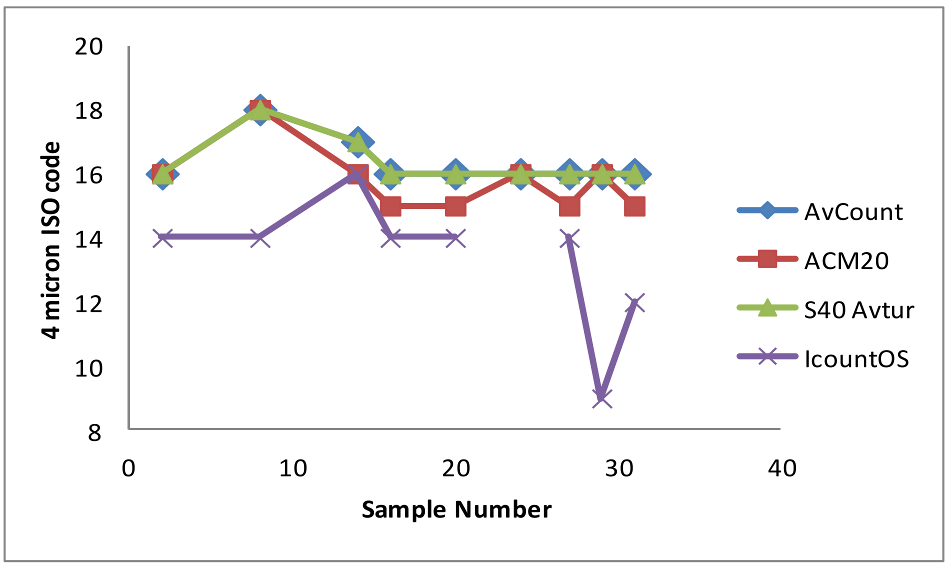

Figure 5. Fort Rucker downstream receipts 4µm ISO code data.

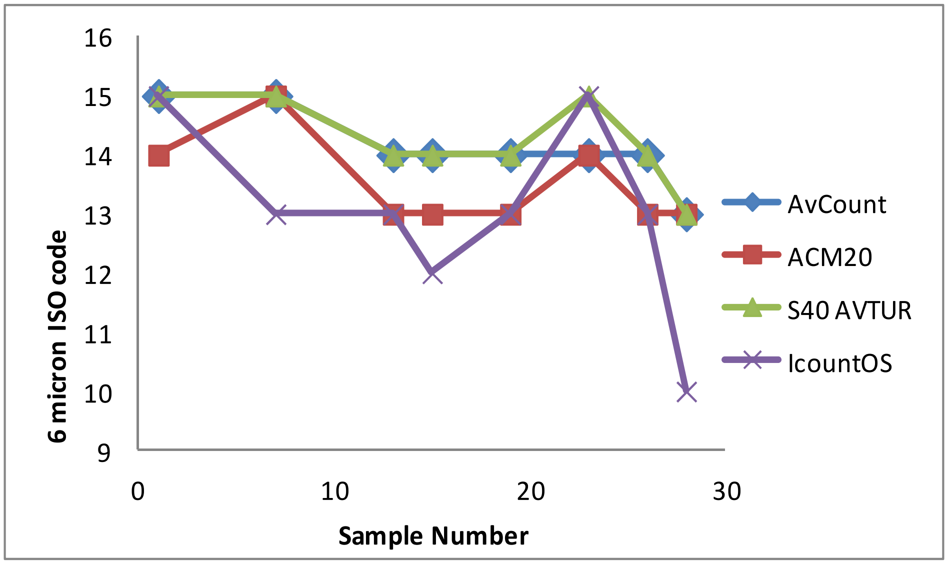

Figure 6. Fort Rucker upstream receipts 6μm ISO code data.

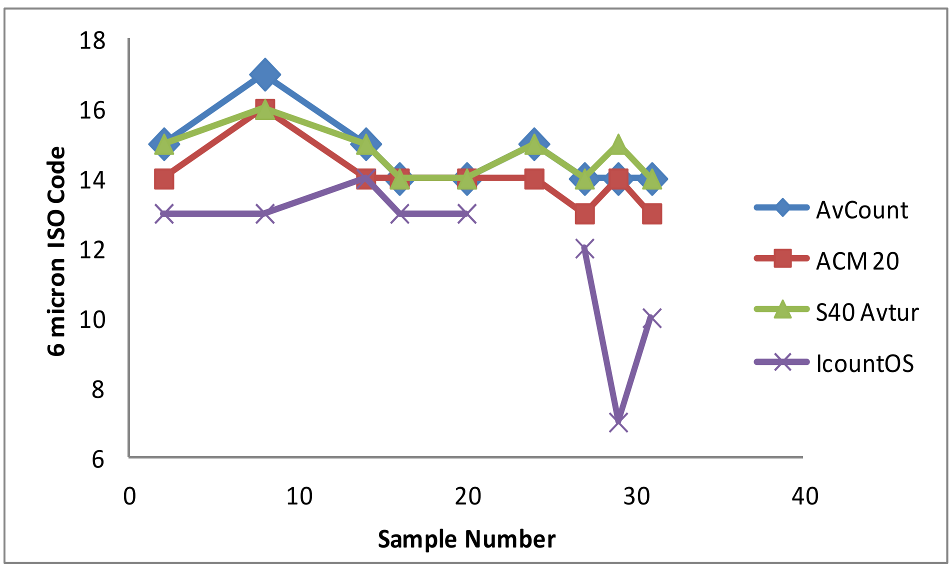

Figure 7. Fort Rucker receipts downstream of filter separator 6μm ISO code data.

All receipt samples at Fort Rucker fell within the Army's proposed cleanliness limit of 19/17/14/13, all the supporting matched weight monitor testing and free water testing also fell within published limits, with the exception of sample 20 which seems to have given an erroneous gravimetric reading given the particle count evidence provided in Table 3 and Figure 12 for this sample.

Time (EST)	*Location*	Sample #	mg/L	Avcount	ACM20	S40 AVTUR	IcountOS
930	upstream	1	0.3	18/15/11/8	17/14/10/6	17/15/11/-	16/15/14/13
930	downstream	2	0.2	16/15/12/9	16/14/11/7	16/15/12/-	14/13/11/7
1400	upstream	7	0.0	17/15/12/10	16/15/12/8	16/15/12/-	14/13/10/9
1400	downstream	8	1.0	18/17/14/10	18/16/13/8	18/16/13/-	14/13/9/6
800	upstream	13	0.8	16/14/10/6	15/13/9/4	16/14/10/-	17/13/9/6
800	downstream	14	0.5	17/15/11/8	16/14/10/6	17/15/11/-	16/14/10/7
930	upstream	15	0.0	16/14/10/7	16/13/10/5	16/14/10/-	14/12/9/6
930	downstream	16	0.0	16/14/11/7	15/14/10/5	16/14/11/-	14/13/9/7
1300	upstream	19	1.0	17/14/11/8	16/13/10/5	16/14/11/-	14/13/11/10
1300	downstream	20	1.7	16/14/11/7	15/14/10/5	16/14/11/-	14/13/10/8
1330	upstream	23	0.7	17/14/11/7	17/14/11/7	17/15/12/-	17/15/13/10
1330	downstream	24	0.4	16/15/11/7	16/14/10/5	16/15/11/-	-
840	upstream	26	1.0	16/14/10/6	16/13/9/4	16/14/10/-	17/13/10/6
840	downstream	27	0.4	16/14/11/7	15/13/10/7	16/14/10/-	14/12/9/7
930	upstream	28	0.1	16/13/9/6	15/13/8/4	16/13/9/-	12/10/6/0
930	downstream	29	0.1	16/14/10/6	16/14/11/9	16/15/11/-	9/7/0/0

Table 3. Fort Rucker receipt laboratory sample ISO code data with initial IcountOS data.

The gravimetric analysis of particulate contaminates data performed via ASTM D2276, is shown in Figure 8 for upstream data and Figure 9 for the downstream data. The data does not show a correlation to the particle counter data, but does show a degree of similar trending with the 4µm upstream data with the IOS data and gravimetric data both dropping in ISO code from the previous samples seen in samples 7 and 16, and an increase is shown with sample 13 but this trending is not significant enough to develop a correlation between the gravimetric and particle counting data.

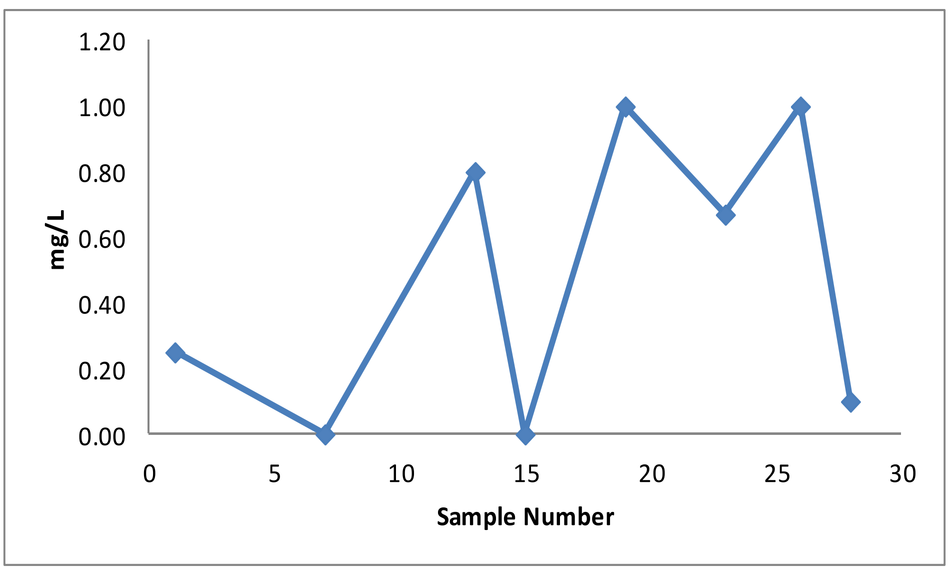

Figure 8. Fort Rucker receipts upstream of filter separator gravimetric analysis.

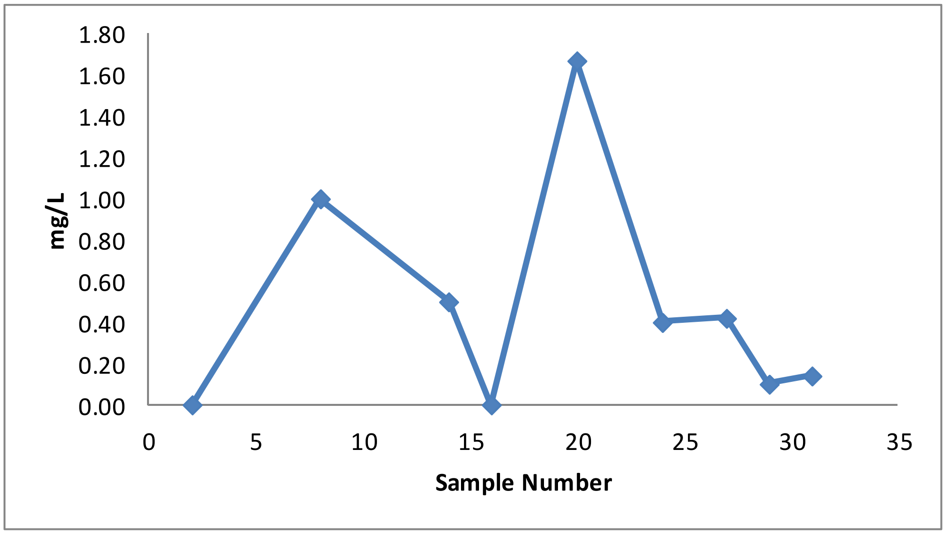

Figure 9. Fort Rucker receipts downstream of filter separator gravimetric analysis.

The analysis of the individual IOS data for the receipt samples showed a lack of homogeneity of fuel contamination throughout the fuel receipt process and indicates that the fuel sampled for the particulate contaminant in aviation fuel by line sampling test may have a different contaminate load than fuel sampled by the particle counters, and that the standard ASTM test method does not provide a representative sample of the fuel as a whole. The IOS data displayed in Figure 10 thru Figure 15 shows the variation of particulate counts during fuel movements and that the fuel downstream of the filter separator does at times appear to carry a higher particulate load than the upstream fuel, the induction of air into the fuel stream (discussed below) may also be the cause of higher particle counts downstream than upstream of the filter separator.

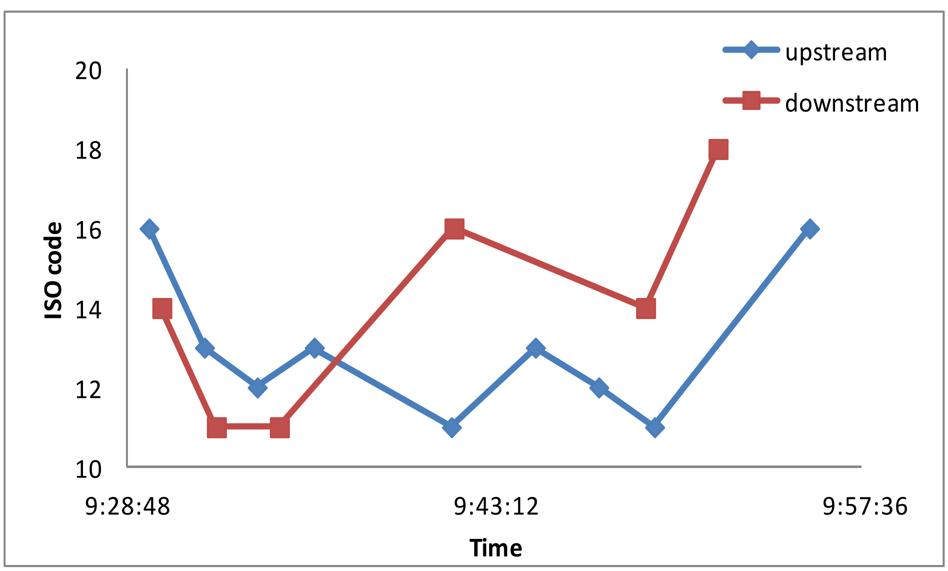

Figure 10. 4 micron IOS data upstream and downstream of receipt filter separator for samples 1 and 2.

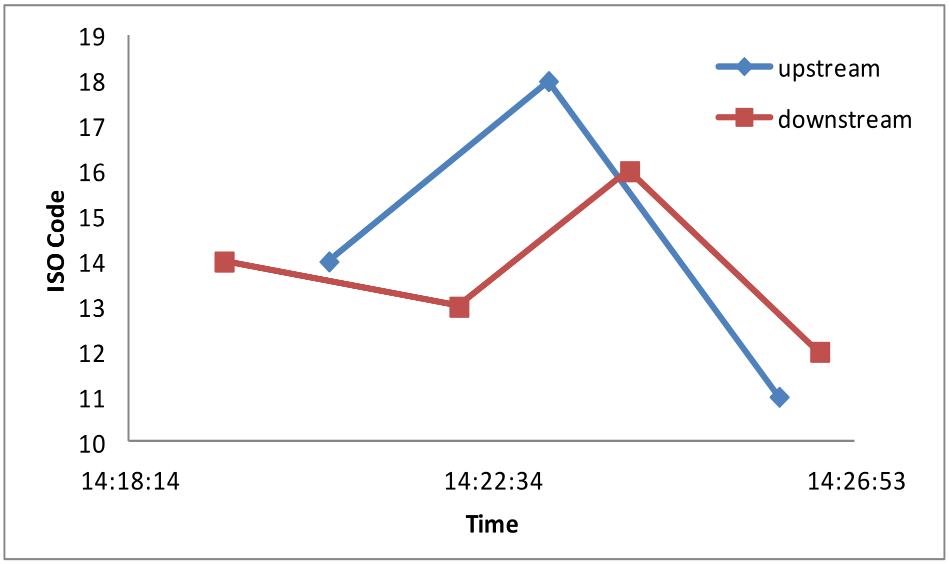

Figure 11. 4 micron IOS data upstream and downstream of receipt filter separator for samples 7 and 8.

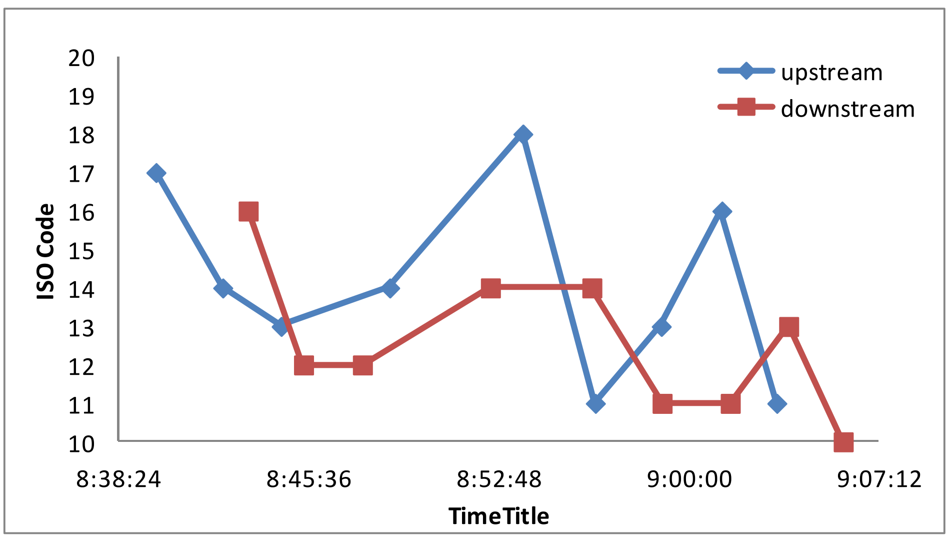

Figure 12. 4 micron IOS data upstream and downstream of receipt filter separator for samples 13 and 14.

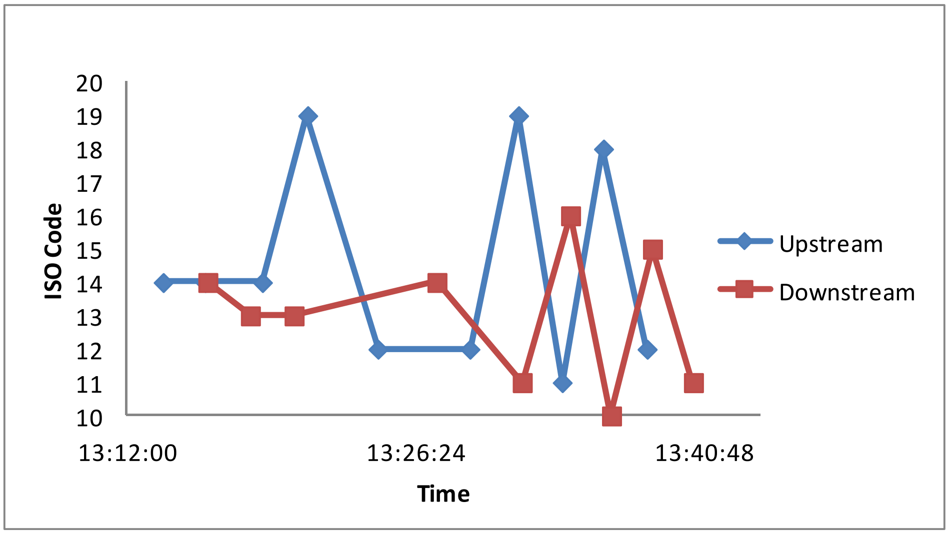

Figure 13. 4 micron IOS data upstream and downstream of receipt filter separator for samples 19 & 20.

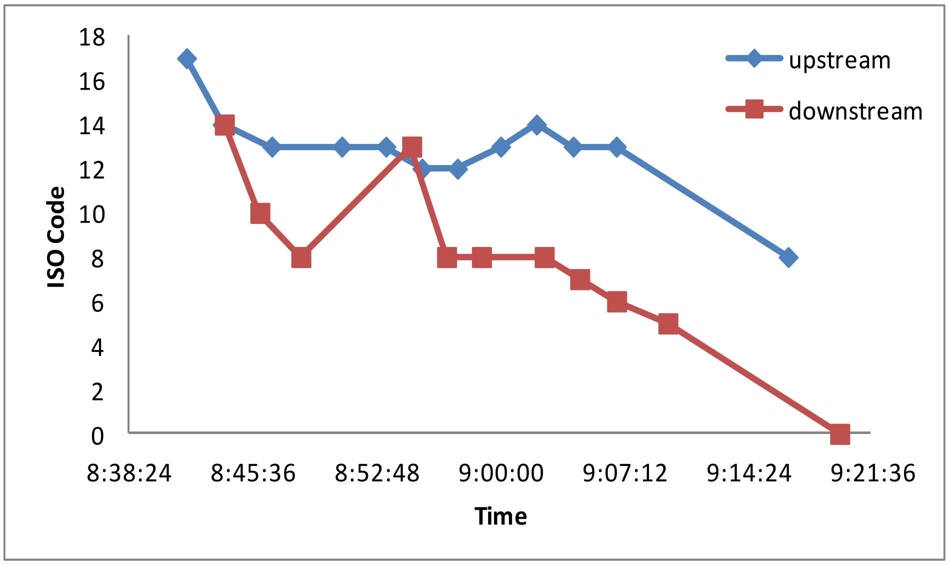

Figure 14. 4 micron IOS data upstream and downstream of receipt filter separator for samples 26 and 27.

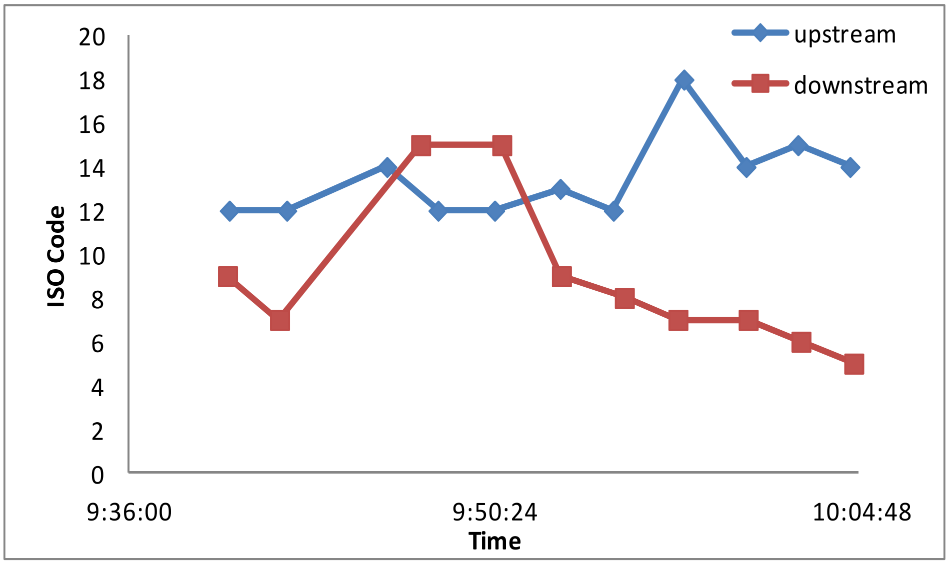

Figure 15. 4 micron IOS data upstream and downstream of receipt filter separator for samples 28 and 29.

When the IOS instruments were allowed to run for an extended period of time during fuel receipt operations at Fort Rucker spikes in the data were observed as shown in Figure 12 above and more clearly in Figure 16 and Figure 17 below, these spikes, present in the 4µm, 6µm, 14µm, and 30µm channels were observed when the unloading hose was changed from one discharge connection to the next on the baffled fuel trucks delivering fuel to Fort Rucker, Figure 18, inducing air bubbles into the fuel stream. The air bubbles were reduced but still present after going through the receipt filter separators, Figure 19 and Figure 20, the presence of the spikes after the fuel has proceeded through the filter separators adds credence to the theory that these abnormalities are caused by air bubbles.

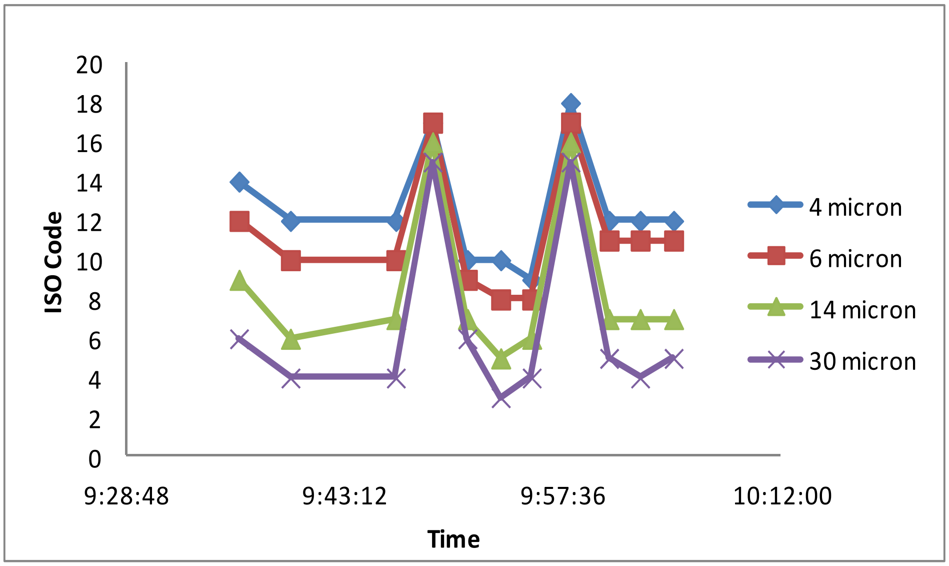

Figure 16. Fort Rucker fuel receipt, sample 15, Hanchey AHP (upstream of filter separator), data spikes present due to air bubbles in fuel.

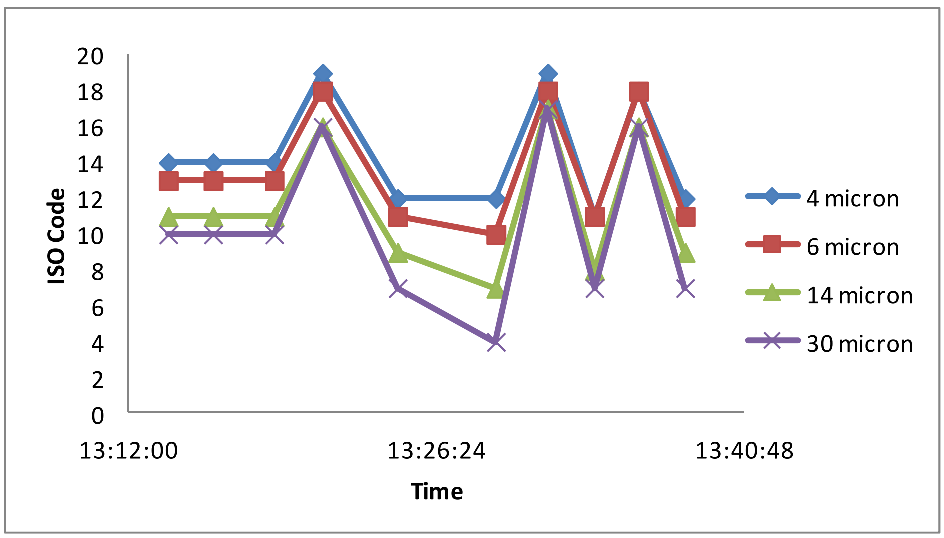

Figure 17. Fort Rucker fuel receipt, sample 19, Hanchey AHP (upstream of filter separator), data spikes present due to air bubbles in fuel.

Figure 18. Fort Rucker fuel receipt from baffled fuel trucks.

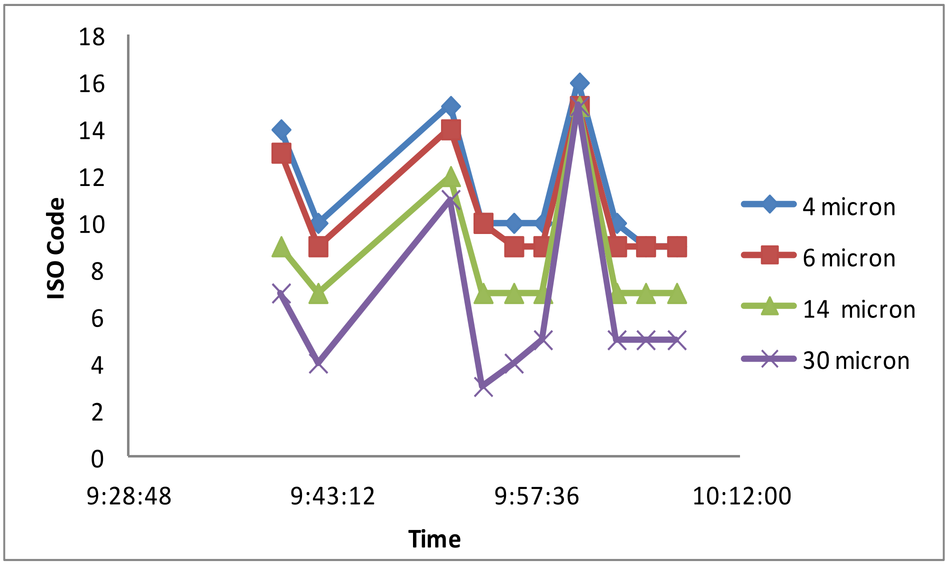

Figure 19. Fort Rucker fuel receipt, sample 16, Hanchey AHP (downstream of filter separator), data spikes present due to air bubbles in fuel.

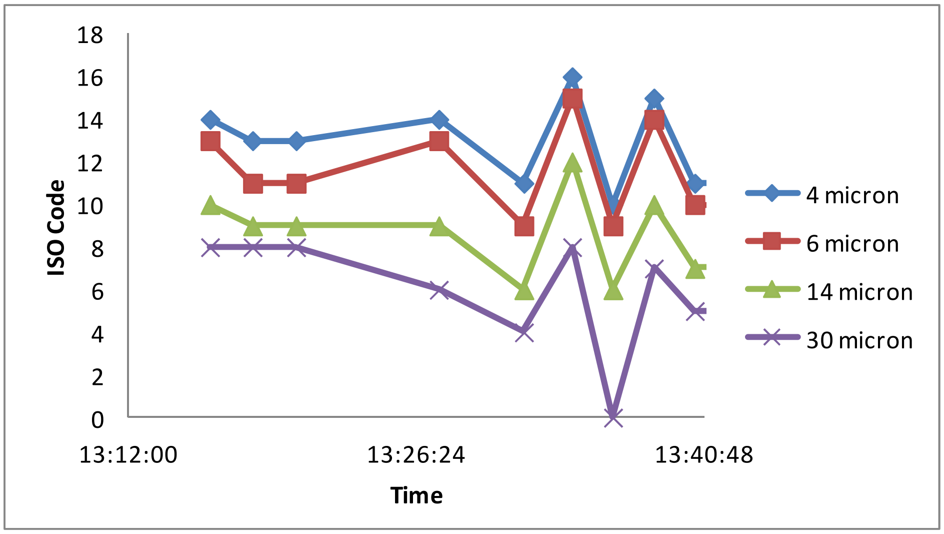

Figure 20. Fort Rucker fuel receipt, sample 20, Hanchey AHP (downstream of filter separator), data spikes present due to air bubbles in fuel.

4.2. Fuel issue data analysis

All issued fuels evaluated at Fort Rucker throughout the evaluation period showed 4µm ISO code particle counts of 16 or less when measured online with the IOS instrumentation as shown in Figure 21 thru Figure 23. With most IOS measurements providing an ISO code reading of 10 or less downstream of the issue filter separator, when this data is compared to the fuel coming in at receipt points seen in Figure 10 thru Figure 15, the fuel handling system in place at Fort Rucker can be seen to be effectively handling the small amount of fuel contamination seen at the Army installation. Table 4 provides the laboratory data and the initial IOS data for the issue samples obtained at Fort Rucker. The variation in IOS data due to different levels of contaminates within the fuel stream coupled with the laboratory data provided in Table 4 which only provides a snapshot of the contaminate levels within the fuel provides additional evidence to the theory that continuous online monitoring is more beneficial than offline measurements.

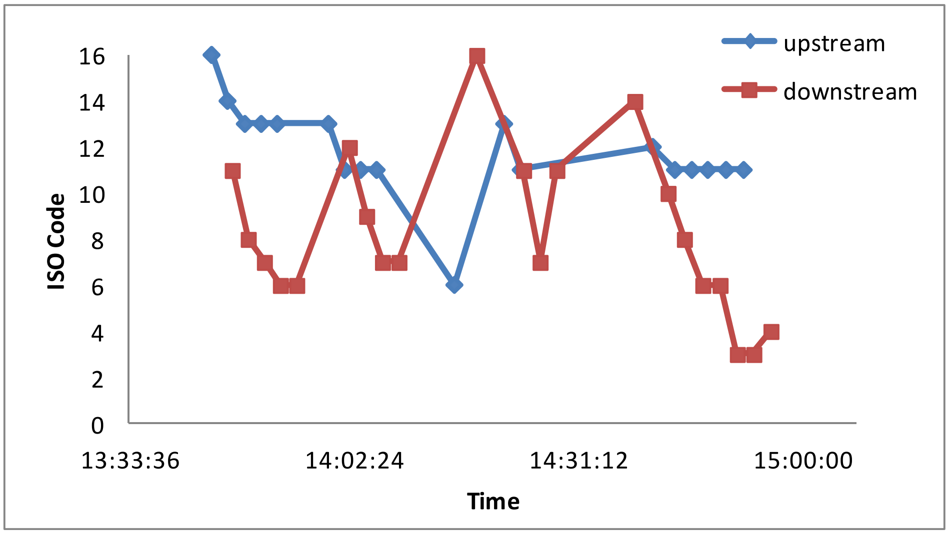

Figure 21. Hanchey AHP issue of samples 3, 4, 5, 6, and 11 & 12.

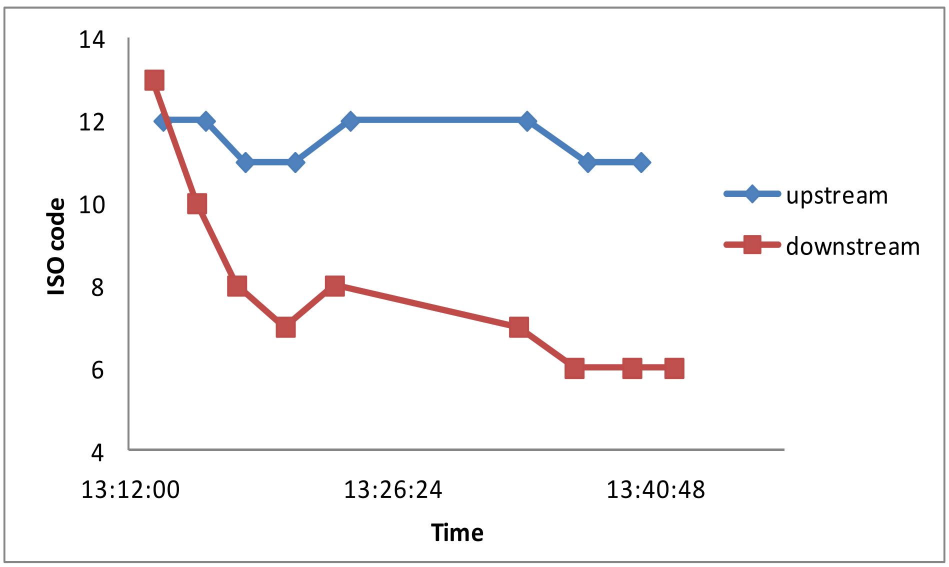

Figure 22. Hanchey AHP issue of samples 17 and 18.

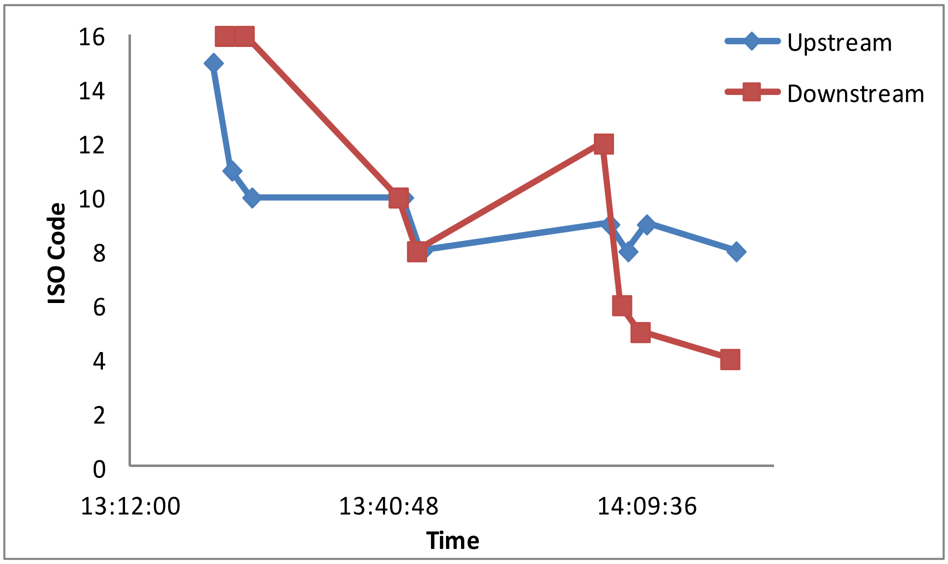

Figure 23. Lowe AHP issue of samples 32 and 33.

Time (EST)	*Location*	Sample #	Avcount	ACM20	S40 AVTUR	IcountOS
1300	upstream	5	17/15/11/7	17/14/10/6	17/15/11/-	15/13/9/7
1300	downstream	4	17/15/12/7	16/15/10/5	17/15/12/-	14/12/9/7
1340	upstream	3	17/15/12/9	17/15/11/7	17/15/12/-	16/14/12/10
1340	downstream	6	15/14/11/8	15/13/10/7	15/13/11/-	-
1355	upstream	11	17/15/12/8	16/14/10/6	16/14/11/-	13/11/7/6
1355	downstream	12	16/14/11/7	16/14/10/6	16/14/11/-	11/10/5/0
1435	upstream	9	17/15/12/9	16/14/11/7	16/15/12/-	-
1435	downstream	10	18/16/14/9	17/16/12/8	18/16/14/-	14/13/11/11
1300	upstream	17	17/15/10/6	17/14/9/5	17/15/11/-	12/11/8/4
1300	downstream	18	17/15/11/6	17/14/10/6	17/15/11/-	13/11/8/6
1320	upstream	32	17/15/11/7	17/15/10/7	17/15/11/-	15/13/10/7
1320	downstream	33	17/15/11/7	16/14/10/6	17/14/11/-	16/14/12/12

Table 4. Fort Rucker issue laboratory sample ISO code data with initial IcountOS data.

4.3. Molinelli Stagefield Army Heliport

In an effort to determine if the particle counter technology can be applied to Army fuel systems for use during helicopter refueling operations, the IOS instruments were taken to Molinelli Stagefield Army Heliport (AHP) which utilizes a hydrant system to hot refuel rotary aircraft at Fort Rucker. The particle counters were installed at Pad 11, which is at the furthest point away from the bulk fuel storage facility at Molinelli Stagefield AHP fed by a 1/3 mile underground fuel line. The IOS data in Figure 24 showed data spikes in all 4 sizing channels at 0925 hrs, 0936 hrs, 0948 hrs, and 0958 hrs. These spikes corresponded to the fuel pump at the airfield automatically shutting off every 10 minutes. These data spikes are very similar to those seen in Figure 16 and Figure 17, it is not believed that there was any air induced into the fuel system at

Molinelli Stagefield AHP, and that they data spikes were caused by the cycling of the fuel pump causing a “water hammer” effect in the fuel system that shook water free from pockets within the fuel system piping. The data spikes are still below the Army’s proposed 19/17/14/13 limits, but it is recommended that the Army evaluate the particle counters on tactical refueling equipment such as the Advanced Aviation Forward Area Refueling System (AAFARS).

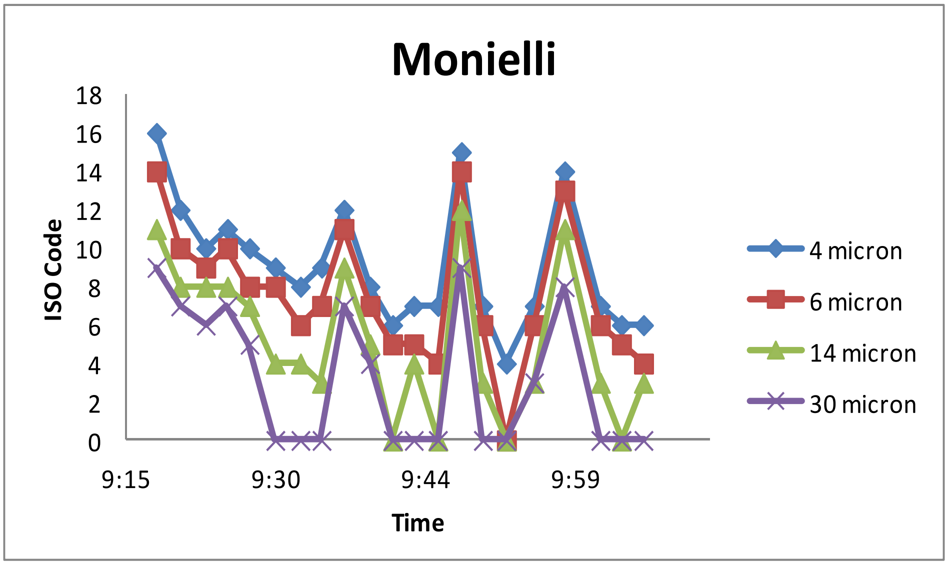

Figure 24. Molinelli Stagefield AHP helipad 11 data spikes present due to water in fuel.

Table 5 provides the laboratory particle counting data for the two samples taken at Molinelli Stagefield AHP. The samples consist of the effluent of the fuel sampled by the IOS instruments and displayed in Figure 24. Laboratory data corresponding to the IOS spikes is theorized to be coincidental, with laboratory data being higher than the average IOS readings due to sample bottle contamination as seen in previous data with laboratory data being up to 4 ISO codes higher for laboratory instrumentation than the IOS instruments. The gravimetric analysis of a sample taken at Molinelli Stagefield AHP was 0.2 mg/L.

Time (EST)	Sample #	Avcount	ACM20	S40 AVTUR
915	21	16/14/11/7	16/14/10/6	17/14/11/-
938	22	16/14/10/7	15/13/9/6	16/13/10/-

Table 5. Laboratory particle counting data of samples taken at Molinelli Stagefield AHP.

5. Conclusion

Light obscuration particle counter technologies are able to properly measure solid particles and provide an indication of particulate content levels present in fuels, and may be an appropriate replacement for the Army’s existing filter effectiveness testing. Data shows that to efficiently monitor filter effectiveness, testing should be completed upstream, as well as, downstream of the filter separator. Particle counts were not correlatable to the gravimetric measurements. All the gravimetric samples having a weight greater than 1.0 mg/L had significant quantities of course particulates contributing to particulate mass. These course particles were not accurately accounted for in the particle count readings. The IOS data shows a non-homogeneity of contamination throughout fuel movements which indicates that the fuel sampled for the particulate contaminant in aviation fuel by line sampling test may have a different contaminate load than fuel sampled by the particle counters, and that the standard ASTM test method does not provide a representative sample of the fuel as a whole.

Significant variation was seen between on-line samples and bottle samples. This variation was shown to be caused by the bottle sampling process. Although almost all fuels fell below the Army's proposed 19/17/14/13 ISO code limits, this limit was developed for on-line sampling, an error window allowing for a higher contamination levels may be appropriate for bottle samples.

Additional testing on tactical fuel handling equipment is recommended to grasp a greater understanding on the amount of air bubbles present in the Army's tactical fuel handling equipment, as evidenced in the Fort Rucker data. The light obscuration particle counters treat air bubbles the same as free water, which could be a problem for the field application of these technologies.

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List of Symbols, Abbreviations, and Acronyms

µm	Micrometer
AAFARS	Advanced Aviation Forward Area Refueling System
AFCTK	Aviation Fuel Contamination Test Kit
AHP	Army Heliport
AL	Alabama
ASTM	ASTM International
AUST	Australia
CAA	Campbell Army Airfield
DEF	Defence/Defense
DLA-E	Defense Logistics Agency – Energy
DTL	Detail
EI	Energy Institute
EST	Eastern Standard Time
hrs	Hours
IOS	IcountOS
ISO	International Organization for Standardization
JP-8	Jet Propellant 8
KY	Kentucky
mg/L	Milligrams per Liter
MIL	Military
PPM	Parts Per Million
STAN	Standard
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States
UK	United Kingdom